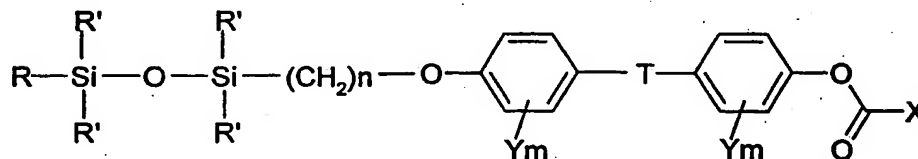


BISTABLE FERROELECTRIC LIQUID CRYSTAL CELLS AND DEVICES  
USING SILOXANE OLIGOMERS AND THE USE THEREOF

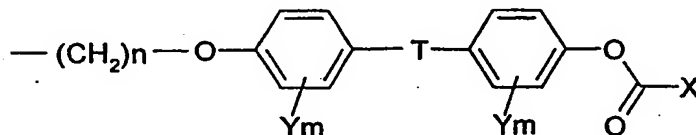
5 The present invention relates to a cell comprising a ferroelectric compound having a smectic C phase, arranged between alignment layers of polyamide or polyester, a device comprising said cell and a process for bistable switching of the device.

10 Ferroelectric liquid crystal (FLC) devices are based on chiral smectic liquid crystals (as described by J. Dijon in Chapter 13 (pages 307-354) of "Liquid Crystals Applications and Uses, Vol. 1, edited by B. Bahadur, published by World Scientific Publishing co. Pte. Ltd (Singapore) in 1990). In particular cells arranged in bookshelf geometry are described (see page 309). These are very thin cells, for example 1 to 10µm thick, arranged between alignment layers. The boundary conditions imposed by the alignment layers are strong enough to suppress the helix structure of the chiral smectic liquid crystal. The smectic layers are generally perpendicular to the cell plates but are capable of switching between two optical states which are at respective angles (the tilt angle) to the perpendicular.

20 US-A-5498368 describes a siloxane- containing compound having the general formula



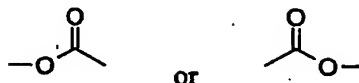
25 wherein R represents an alkyl group having from 1 to 10 carbon atoms or the group



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each R' represents an alkyl group having from 1 to 4 carbon atoms, T is



5 X represents an alkyl or halogen-substituted alkyl group having at least one chiral centre, Y represents a fluorine atom, m has a value of 0, 1 or 2 and n has a value of 10, 11 or 12.

10 The ferroelectric liquid crystal siloxane oligomers of US-A-5498368 exist as neat compounds or in mixtures which exhibit relatively high tilt angles. Measurements of the tilt angle of other liquid crystal materials, as disclosed in JP-A-01-144491 have shown not only a variation from polymer to polymer but also a reduction of the tilt angle with increasing temperature. The tilt angles of the ferroelectric liquid crystal materials of US-A-5498368 are substantially independent of temperature over a broad  
15 temperature range including ambient.

However, none of the cell structures disclosed in the art provide a bistable device which can be used in practical applications for example for use in large area FLC display panels, real time holographic devices, etc. There is therefore a need in the art  
20 for the development of such bistable materials.

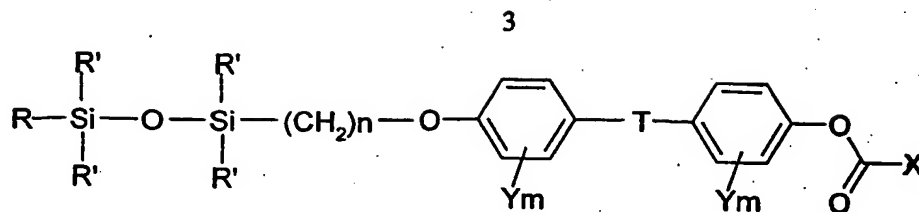
We have found according to the invention that a high quality bookshelf FLC structure comprising a ferroelectric siloxane oligomer (including the oligomer disclosed in US-A-5498368) can be simply made and switched in a bistable fashion.

25 According to the first aspect of the invention there is provided, a bistable liquid crystal cell comprising a smectic C siloxane-containing compound arranged between alignment layers of polyamide or polyester, said siloxane-containing compound having the general formula

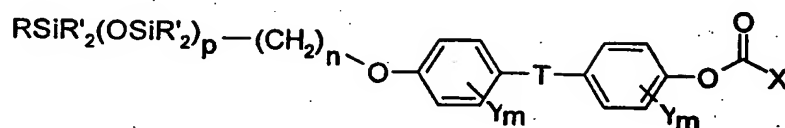
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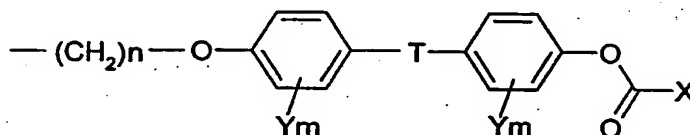
alignment layers of polyamide or polyester and siloxane-containing compound



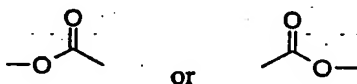
or



wherein R represents an alkyl group having from 1 to 10 carbon atoms or the group



each R' represents an alkyl group having from 1 to 4 carbon atoms, T is



X represents an alkyl or halogen-substituted alkyl group having at least one chiral centre, Y represents a fluorine atom, m has a value of 0, 1 or 2, p has a value of 2, 3 or 4 and n has a value of 10, 11 or 12.

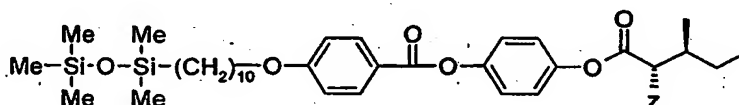
For the purposes of the present invention, the term "bistable" indicates that no substantial relaxation of the two possible switched states (i.e. the metastable states into which the molecular system can be forced by a control signal) of the liquid crystal can be observed.

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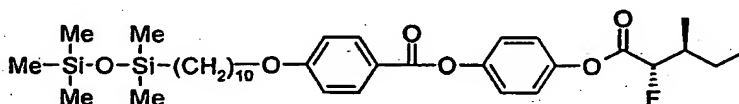
The ferroelectric liquid crystal siloxane oligomers of the invention do not have smectic A or nematic phases; the smectic C phase is formed directly on cooling from the isotropic state. The most preferred ferroelectric liquid crystal siloxane oligomers of the invention are those of the formula where Z is Cl or F

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The ferroelectric liquid crystal siloxane oligomer is most preferably,

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The crystal cell of the first aspect can further comprise one or more further ferroelectric liquid crystal materials. The further ferroelectric liquid crystal can be provided in combination with the smectic C siloxane-containing compound, preferably in a mixture thereof. The further ferroelectric liquid crystal is preferably provided at a level of 50% or below, more preferably 20% or below, most preferably 5% or below of the further ferroelectric liquid crystal-smectic C siloxane containing compound mixture.

Although we do not wish to be bound by any particular theory, we believe that the ability to achieve bistable switching is at least partly due or is enhanced by providing only a weak interaction, that is to say weak coupling, between the alignment layers and the surface layer of the smectic C phase immediately adjacent to the alignment layers and/or only a weak interaction between the various layers of the smectic C phase, especially between the said surface layer of the smectic C phase and the next adjacent layer of the smectic C phase. The nature of the alignment layer and/or the siloxane ferroelectric compound should be chosen accordingly. In the case of the alignment layers, layers made of polyamide and polyester are preferred.

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The alignment layer is preferably a polyamide. The preferred polyamide is nylon-6,6, although nylon-6 is an alternative. Polyester alignment layers are also suitable, particularly an aliphatic/aromatic polyester such as a polyalkylene terephthalate, for example PET (polyethyleneterephthalate) or PBT (polybutyleneterephthalate).

5 Polyimide alignment layers, which are the most commonly used alignment layers for liquid crystals, have not been found to allow bistable switching by application of an electric field alone without temperature change. The cell of the first aspect can be prepared according to methods and/or processes known in the art.

10 The present invention further provides, in the second aspect, a device comprising a cell as described in the first aspect of the invention. The device is preferably a multiplexed FLC large panel display or a liquid crystal on silicon (LCOS) device. The device of the second aspect can be prepared according to methods and/or processes known in the art.

15 The initial alignment of the liquid crystals can be brought about by applying an electric field having a value between 2 to 50V per  $\mu\text{m}$  cell thickness at a frequency having a value between 1 to 10KHz. The invention also includes in the third aspect a process for bistable switching of a ferroelectric liquid crystal device, in which a cell  
20 as defined above for the first aspect is switched by applying an electric field having a value between 2 to 50V per  $\mu\text{m}$  cell thickness.

Such voltages can be made available in multiplexed FLC large panel displays or in liquid crystal on silicon (LCOS) devices so devices may be aligned, and if necessary  
25 restored in situ. This offers a new route to bistable switching, other than the conventional methods of either sheer alignment (which is not applicable to display manufacture) or cooling down to the smectic C phase via nematic and smectic A phases.

30 Advantages of the invention include that no heating/cooling cycles are required to create the alignment required for bistable switching. Hence re-alignment can be

carried out during the life of manufactured FLC displays if necessary. Display devices that have had their surface induced alignment damaged (e.g. by shock, deformation or temperature excursions) may be routinely repaired (e.g. during device start-up or shut-down) in service.

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Since the materials do not have overlying smectic A or nematic phases, the tilt angle (and therefore the switching angle) is high and temperature independent. The formation of chevrons and related defects is not observed. Only such FLCs that exhibit the chiral smectic C through such a first order transition are capable of giving the 45 degree tilt angles that are necessary for efficient phase modulation. Previously there has been no practical method of making such materials truly bistable. Embodiments of the cells of this invention can be used for the display industry (with tilt angles near 22.5 degrees) as well as for real time holographic devices using phase modulation (with tilt angles approaching 45 degrees). The tilt angle obtained is chosen by selection of the mesogen present in the ferroelectric liquid crystal siloxane oligomer of the invention

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Electro-optic bistability is the basis of the remarkable ability of FLC displays to be passively multiplexed (i.e. to operate without positioning transistor circuitry at each pixel). Achieving robust bistable surface alignment has been a major uncertainty in developing large area FLC display panels. In LCOS displays which do have an active backplane which effectively speeds up the frame time we believe that only bistable FLC devices can have a continuously valid image. As far as we know all commercial FLC LCOS devices do not rely on bistability and hence have to "switch off" the illumination at intervals. As the cells of the invention are truly bistable, they can have a continuously valid image.

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Bistability is also required for the use of FLCs in devices for storing or accumulating information, e.g. optically addressed spatial light modulators for ultra high resolution displays for holographic systems. Latching switches for telecommunications applications also need to be bistable.

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Layer rotation of the bookshelf structure can be achieved by application of an electric field with an asymmetric waveform, as described by I.G.Magnolis et al in the paper "Control of the electro-optic bistability of some useful FLCs useful for binary phase optical modulators" in Mol. Cryst. Liq. Cryst., 351, (2000) at page 305. Layer  
5 rotation with retention of a truly bistable material has not previously been achieved.

All preferred features of each of the aspects of the invention apply to all other aspects *mutatis mutandis*.

10 The invention may be put into practice in various ways and a number of specific embodiments will be described by way of example to illustrate the invention with reference to the accompanying drawings, in which:

Figure 1 shows the structure of the cell as illustrated in schematic cross-sectional  
15 view. The siloxane-containing crystal material (117) is interposed between a pair of substrates (110, 111) which may be constructed of glass or a suitable polymer. The inner surfaces are coated with a transparent conducting film (112, 113) of, for example, indium tin-oxide and aligning agent (114, 115). The aligning agent (114, 115) is preferably polyamide or alternatively PET or PBT in the cell of the present  
20 invention. Spacers (116) define the cell thickness. The conducting film may cover the whole inner surface of the substrate or may be etched into a suitable pattern.

Figure 2 shows the consequences of the SmC\* to isotropic transition.

25 Figure 2(a) shows the stability of the tilt angle at temperatures in the range 25 to 50°C.

Figure 2(b) shows the electrooptic response of the cell to an applied voltage varying between +7 and -7V.

30 Figure 3(a) is a photomicrograph of the siloxane oligomer in the cell before and after alignment by electric field, showing the bookshelf structure achieved after alignment.

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Figure 3(b) shows the structures before and after alignment of a commercial FLC aligned by prior art methods.

Figure 4 illustrates the bistable switched states of chiral smectic C experimental siloxane oligomers CDRR<sup>3</sup> and CDRR<sup>8</sup>.

Figures 4(a) and (b) are photographs of light taken through the cell between crossed polarisers in the positively and negatively switched conditions. Figure 4(a) shows that light is transmitted in one state (the bright state) whereas Figure 4(b) shows that no light is transmitted in the other state (the dark state). The observed behaviour suggests decoupling from the surface due to long siloxane chains. This is also suggested by layer rotation.

Figures 5(a) and (b) show asymmetric waveforms which can be used to induce layer rotation of the FLC in the cell, as described in the Mol. Cryst. Liq. Cryst. 351, 205, 2000.

Figure 6(a) shows the voltage applied to the cell over time. Positive voltage is applied so that the FLC is aligned in its bright state followed by no voltage then negative voltage. Figure 6(b) shows the response of a photodiode to light from crossed polarisers passing through the cell. The response is positive (light is transmitted) after application of the positive voltage and substantially stable while no voltage is applied and drops to zero when a negative voltage is applied.

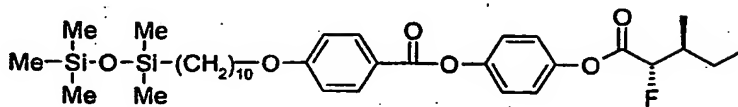
Figure 6(c) also shows the voltage applied to the cell over time. In this case negative voltage is applied so that the FLC is aligned in its dark state followed by no voltage then positive voltage. Figure 6(d) shows the response of the photodiode. No response is recorded (no light is transmitted).

The present invention will now be illustrated by reference to one or more of the following non-limiting examples.



Example

A ferroelectric liquid crystal siloxane oligomer of the formula



10 (CDRR8) was assembled in a cell of the type shown in Figure 1. The cell was 2μm thick. The alignment layers 14, 15 were rubbed polyamide layers 20nm thick. The cell was heated to above 53°C to convert the siloxane oligomer to the isotropic state and cooled to form the smectic C phase. An electric field of 20V at frequency 1KHz was applied.